Sediment Flux to the Coastal Zone: Predictions for the Navy

James P.M. Syvitski,
Environmental Computation and Imaging Group, INSTAAR, Univ. of Colorado, Boulder CO, 80309
phone: (303) 492-7909   fax: (303) 492-3287   email: syvitski@colorado.edu

Charles J. Vörösmarty,
Water Systems Analysis Group, ISEOS, University of New Hampshire, Durham NH, 03824
phone: (603) 862-1792   fax: (603) 862-0188   email: charles.vorosmarty@unh.edu

LONG-TERM GOALS

Determine the magnitude, seasonality, and geographic distribution of mine burial rates, as a function of landward and seaward forces. The central premise is that the nature of upland drainage basin characteristics (including human forcings) defines the spatial distribution, timing, frequency and intensity of river-dominated fluxes of suspended sediments. Develop a set of quantitative estimates of continental-scale suspended sediment flux that can be derived from currently available global biogeophysical data sets. Determine the accuracy of these simulated outputs through comparison to measured fluxes.

OBJECTIVES

1. Develop a compendium of global and regional databases in a GIS system. Optimize for sediment flux analysis (e.g. high-resolution river networks, geological maps of source areas, ocean currents, wind vectors).

2. Develop an approach that is global in scope for determining the potential burial rate using "quick look models".

3. Develop burial models at the regional scale, at specific locations, after consulting synoptic models. These models should provide reliable forecasts based on coupled-processes including meteorological and oceanographic conditions of river discharge, wind, waves, tides, and coastal currents, and their duration and variation for coastal areas.

4. Evaluate the seasonal to decadal large-scale seabed deposit cycles through an exploration of inter-annual variability and controls of continental transports.

APPROACH

Develop an approach to predicting the flux of sediment from land to the sea at 1/2° cells for the global coastline. Develop an approach to predicting sediment-dispersal patterns at 1/2° cells.
a) Annual mean conditions (with interannual variations). Describe the coastline in terms of low,

medium and high sedimentation rates, with an analysis of the factors causing these spatial variations.

b) <u>Seasonal influences</u>. A coastal environment may experience one or more seasons where ocean conditions are stable, and river discharge is low. Other possibilities include: 1) high flux of sediment, calm ocean conditions; 2) low sediment flux, stormy conditions; and 3) high sediment flux, stormy conditions.

c) <u>Extreme events</u>. Develop a mine-burial probability density function, through an examination of flood potential for major seafloor perturbations. For example, the Eel River in 1964 discharged more sediment in 3 days than the previous 8-yr. combined. In contrast, the Amazon River has small annual and interannual variability in terms of sediment flux to the Atlantic Ocean.

d) <u>Influence of man</u>. Develop models that will include the effect of man on discharge to the coastal zone, for example the sediment load to the China Sea when the Three Gorges Dam comes on line.

WORK COMPLETED

Global and Regional Database development:
- Developed a GIS-based drainage basin characterization system for drainage basins, with 20 classes of spatially distributed data sets used to quantitatively describe > 6000 individual drainage basins in our global data compendium at 0.5° (lat., long.) spatial resolution.
- Established the verification data for our model for the entire non-glacial landmass of the Earth (Fekete et al. in press).
- Mounted our data (www.watsys.sr.unh.edu, www.r-hydronet.sr.unh.edu) including regional databases (Lammers et al. 2001); Vörösmarty et al., 2000c).
- Developed an appropriate typology of river systems by which we can take information on well-monitored basins and extrapolate to more poorly understood areas of the globe (e.g. Meybeck et al. 2001a, b, and in press).
- Developed method for up-scaling river networks (Fekete et al. 2001).
- Set up relational and spatial databases, and determine a streamlined procedure to link these databases to drive *HydroTrend* in an automated way, i.e.:
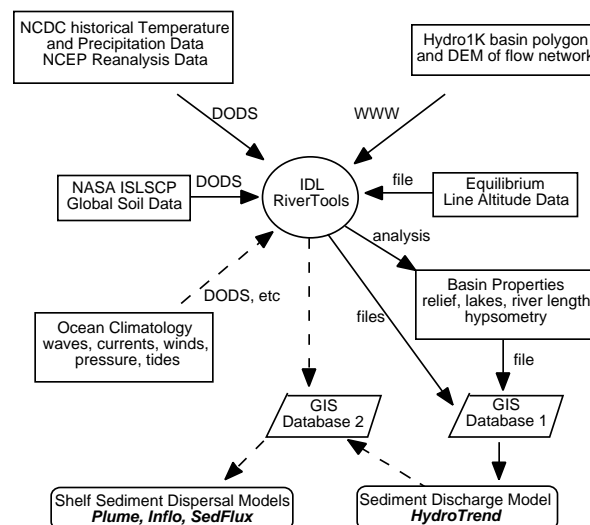
Data ingestion scheme for predicting sediment dispersal on continental shelves (see text).

To facilitate extracting climate data, the Distributed Oceanographic Data System (*DODS*) (http://www.unidata.ucar.edu/packages/dods/) is employed as a client on *IDL* (Interactive Data Language, which translates data from the server's *API* (Application Program Interface) to the client's *API*, thus eliminating the reformatting of data. *HYDRO1k*, a 1km global Digital Elevation Model (http://edcwww.cr.usgs.gov/landdaac/gtopo30/hydro/index.html) defines the coverage of stations within the hydrological boundaries of a given basin to query the *DODS* servers. Temperature and precipitation data are derived from NOAA NCDC databases that offer data for 10,000 stations (1977-1991 and variably 1697-1995). NCEP/NCAR Reanalysis database, from NOAA-CIRES-CDC (http://www.cdc.noaa.gov/cdc/data.ncep.reanalysis.derived.html) provides the grid of global lapse rates (change in temperature with elevation). Topological parameters (hypsometric curve, basin length, area, slope, and relief) are extracted for specified basins from *HYDRO1k* through *ArcInfo* and transferred into *RiverTools*. Extraneous databases needed for hydrological modeling include: (1) CCM3 Equilibrium Line Altitudes from glaciers world-wide; and (2) IGBP-DIS global soil database including water holding capacity, field capacity, soil depth, slope, % grain sizes and bulk density (http://www.daac.ornl.gov/SOILS/IsricGrids.html).

Development of indices of fluvial influence (IFI)
Developed computer codes to assemble each day the entire near-real time archive of the US Geological Survey to assess the size of river plumes in conjunction with satellite ocean-color sensors (Salisbury et al. 2001). The coastal plume approximates the sediment dispersion area of river discharge. Covariance models consider how remotely sensed concentration estimates (e.g. sediment or chlorophyll) co-vary with nearest river's discharge. (Salisbury et al., 2001). The spatial-temporal variability in the Mississippi's sediment plume was documented using temporal-temporal covariance modeling of discharge, wind and ocean color fields (Salisbury et al., 2002).

Riverine Sediment Trapping
The global geography of basin-wide trapping of suspended sediment flux by large reservoirs has been analyzed in this study. A residence time change for otherwise free-flowing river water is determined locally for 633 of the world's largest reservoirs ($= 0.5 \text{ km}^3$ maximum storage capacity) and used with a sediment retention function to predict the proportion of incident sediment flux trapped within each impoundment (Vörösmarty et al, 2002).

Potential burial rates using "quick look models"
"Quick look" products that define the nature of land-to-sea linkages are available at http://www.watsys.sr.unh.edu. To better quantify the human impact on sediment flux, we developed a framework for routing sediment through river basins with simultaneous consideration of siltation in artificial impoundments and the influence of anthropogenic water consumption through activities such as irrigation (Vörösmarty et al., in press). It is estimated that humans trap 30% of river sediment through reservoirs.

Seasonal Flux Estimates
Preliminary estimates of seasonal fluxes of sediment from all global rivers with drainage basins larger than $10,000 \text{ km}^2$ have been completed. This model is currently undergoing verification and expansion to monthly time step.

Potential burial rates at the regional scale, at specific locations
HydroTrend is upgraded (v.2.1) to provide daily sediment flux estimates for almost any river, whether gauged or not (Morehead et al., in press). The model is driven by climate measurements or with

statistical estimates of climate. *HydroTrend* is able to examine the effects of weather systems on the supply of sediment to continental margins, and thus the nature of supply variability. When applied to Arctic and sub-Arctic rivers as a test of its ability to handle complex hydrologic processes (snow melt, ice melt, rainfall, groundwater discharge), the model could estimate the annual sediment flux to within a factor of 3 (Syvitski, in pressb). The model has also been applied to temperate rivers like the Mississippi River (Fig. 4) and found to accurately capture the daily variability in sediment flux (Morehead et al., in press).
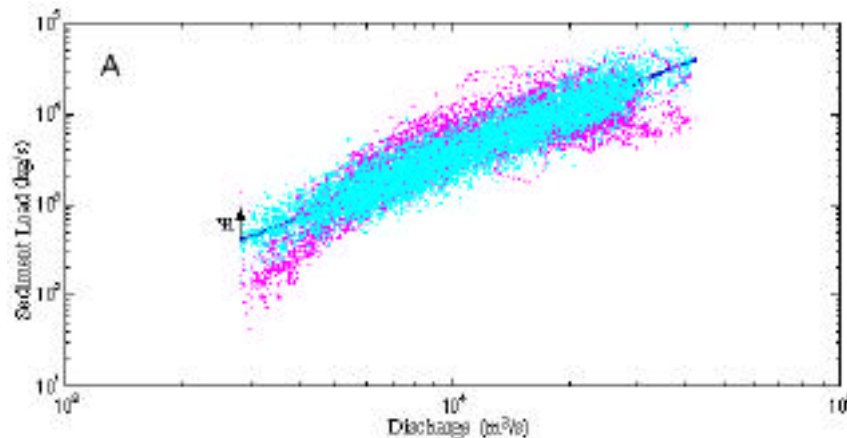
Predicted (light blue) versus observed (pink) daily sediment load of the Mississippi River (30 year record) (after Morehead et al., in press).

Seasonal to decadal seabed deposit cycles through an exploration of inter-annual variability and controls of continental transports
Morehead et al. (2001) were able to predict both the grain size (±10%) and the accumulation rate (±30%) of sediment with seaward distance from shoreline for Eel River systems and for the Knight Inlet, two relatively small rivers that drawn the west coast of North America.

RESULTS

Present mine burial models are deficient because they: (1) are empirical rather than physics-based, (2) contain no time dependence, and (3) require environmental observations in the vicinity of the mine position. Some of the ongoing Mine Burial modelers address the first issue. Others address the second and third deficiencies, developing data ingestion and predictive techniques to describe the time-dependent environmental conditions at potential mine burial sites. This includes wave forecasts using WAM or WWIII (Friedrichs and Wiberg), and sediment flux predictions (this study). Quantitative predictions of mine burial require realistic estimates of the sediment supply to the local environment from rivers. Despite its importance, Mine Warfare Pilots do not yet include environmental information on river discharge or sediment loads.

Linking global data sets to data ingestion schemes allow our sediment transport models to provide to insight into both spatial and temporal variability of the flux of sediment to the margins of continents. Where data is not available, we have developed methods or models to predict solutions and complete the entire schema. While the schema remains in the research development mode, code is available to the ONR mine burial community. A new model for predicting the long-term and intermediate (monthly) flux of sediment from river basins to the coastal ocean successfully predicts the flux of

sediment to within one standard deviation for 70% of the world rivers with observations, across a range of five orders of magnitude. The remaining 30% of the rivers are predicted to within an order of magnitude when compared to observational data that itself has an estimated error of ±200%. The model is based on the geographic location of the drainage basins, and their physical attributes (relief, area). Average basin temperature is predicted (±2.5°C) from the location (latitude, longitude) of the basin area and relief using a hypsometric approximation. The sediment flux model incorporates climate through basin temperature and incorporates estimates of hydrologic runoff through a linked model that relates regional discharge to drainage area. Solutions are provided for each of the major hemispheric climate (polar, temperate and tropic) regions.

Two important areas of development that remain are: (1) providing a method for temporal coherency between climatological events, such as rain days, when the model is run in the statistical mode, and (2) averaging the spatial distribution of climate values from unrepresentative climate stations.

IMPACT/APPLICATIONS

New numerical tools are being refined to allow for predicting the flux of sediment to the littoral zone. Because these tools are driven by environmental data they offer the promise to provide seafloor information of continental margins at the global level.

RELATED PROJECTS

ONR Geoclutter: Predicting the Distribution and Properties of Buried Submarine Topography on
    Continental Shelves.
ONR STRATAFORM: Scaling and Integration of Process-Response Stratigraphic Models.
ONR EuroSTRATAFORM: Modeling the Effect of Climatic and Human Impacts on Margin
    Sedimentation.
ONR Uncertainty: Seabed Variability and its Influence on Acoustic Prediction Uncertainty.
NSF MARGINS: Experimental and Theoretical Study of Linked Sedimentary Systems.
NSF MARGINS: Community Sedimentary Model Science Plan for Sedimentology and Stratigraphy.

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